The weighting step in life cycle impact assessment
Three explorations at the midpoint and endpoint level

Weighting with damage costs

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Summary
This report discusses weighting with an approach in which environmental damage is translated into monetary terms. Different interpretations of terms like "damage" and "cost" are discussed, and different techniques for estimating these costs are presented. A literature review of the estimates of monetary damage for the three endpoints of ReCiPe then leads to a summary table of weighting factors. At the same time, it is concluded that there is so much uncertainty, and that the uncertainty is moreover unknown itself, that users of these weighting factors are advised to be very careful.

1 Introduction

This is one of a series of three reports on weighting in life cycle assessment (LCA). The reports have been produced in a joint project for the Dutch Ministry of Environment (VROM) by PRé Consultants, CE Delft, and the Institute of Environmental Sciences at Leiden University (CML). Although discussions have taken place with PRé Consultants and CE Delft, this report is written by CML.

The report is written within the context of a series of three projects, jointly known as ReCiPe. These projects aim at developing life cycle impact assessment (LCIA), and in particular at integrating midpoint and endpoint methods for characterization, for improving and updating normalization, and for exploring weighting.

This report discusses weighting with an approach in which environmental damage is translated into monetary terms. We first discuss the principles of the method, then proceed to the details of estimating damage costs, and finally give a number of results from literature.

2 Basic principle of the method

The basis of the damage cost approach is that environmental impacts cause a damage to various safeguard subjects, such as human health, ecosystem quality, natural resources, and the man-made environment, and that the subjective importance of these types of damage can be measured by the value than man assigns to it. This value, in turn, can be expressed with a monetary value. With this, different types of damage can be converted into the same, monetary, unit and aggregated into one overall damage indicator.

Thus, denoting the impact for a certain category *cat* by $impact_{cat}$, and the cost of that impact category per unit of impact by $cost_{cat}$, we can aggregate the different types of impact into one overall damage value by

$$damage = \sum_{cat} cost_{cat} \times impact_{cat}$$

The use of damage costs has been used in a large number of studies. For instance, the ExternE project states on its website (http://www.externe.info/) the following:
Human activities like energy conversion, transport, industry, or agriculture cause substantial environmental and human health damages, which vary widely depending on where the activity takes place and on the type of the activity. The damages caused are for the most part not integrated into the pricing system. Borrowing a concept adopted from welfare economics, environmental policy calls these damage costs externalities or external costs.
and:

An external cost, also known as an externality, arises when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group. Thus, a power station that generates emissions of SO_2, causing damage to building materials or human health, imposes an external cost. This is because the impact on the owners of the buildings or on those who suffer damage to their health is not taken into account by the generator of the electricity when deciding on the activities causing the damage. In this example, the environmental costs are "external" because, although they are real costs to these members of society, the owner of the power station is not taking them into account when making decisions. Note that external costs are unintended and result from there being no property rights or markets for these environmental effects.

Thus we see that we have to distinguish between damage costs and external costs:

- damage costs are costs associated with the damage caused by certain activities, these can be internal or external;
- external costs are costs that are not part of the market price, these can be related to damage but also to "normal" costs

As a side remark, externalities are not only costs, but can also be benefits. An increased CO_2-concentraion, for instance, has positive externalities on certain agricultural activities. Obviously, both cost and benefit are in this case unintended.

It is important to highlight that terms like "weighting on the basis of monetary value" or "monetarized weights" are inappropriate in the present context. Given the report by CE Delft that accompanies this report (De Bruyn et al., 2007), we have to distinguish at least:

- weighting on the basis of prevention costs;
- weighting on the basis of damage costs.

Both can be regarded as weighting on the basis of monetarized values. The big difference is, however, that prevention costs are costs of hypothetical abatement or mitigation measures that could be taken, but that are actually not taken. When no prevention takes place, a large damage will occur, and when full prevention takes place, no damage will occur. So we get a picture like Figure 1.

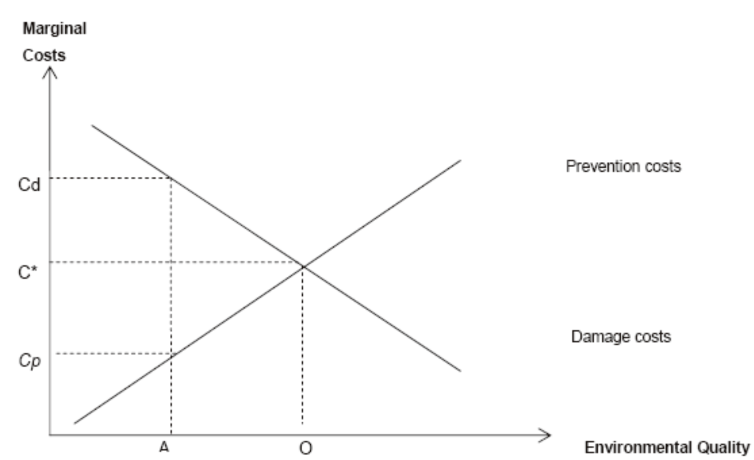

Figure 1. Relation between damage costs and prevention costs. The actual environmental quality (A) is lower than the optimum (O). Notice that O is an optimum in an anthropocentric, welfare-theoretic sense. The actual damage cost C_d is higher than the optimal damage cost C*.Source: De Bruyn et al., 2007.

The damage-cost approach has some problems (De Bruyn et al., 2007):

- damage cost function are often represented by extremely simplified linear functions[1];
- damage cost function are very incompletely estimated.

On the other hand, a prevention-cost approach suffers from problems as well. To mention just two:

- prevention costs are policy/target dependent;
- prevention costs are technology dependent.

As such, monetarization in terms of prevention costs provides an approach that is more contingent than monetarization in terms of damage costs.

As a closing remark, damage costs and prevention costs do not provide the only ways to monetarize environmental problems. For instance, Welsch (2006) uses subjective respondents' reports on "well-being", to correlate changes in environmental quality with changes in income.

3 Operational implementation of the method

In order to use the damage cost method, an estimate of the costs per unit of damage for every impact category must be made.

Although it at a first glance sounds straightforward to express damage in monetary terms, there is quite some choice of options in determining the monetary value of damage. We mention two wide categories:

- based on market values;
- based on non-market values.

Within the first group we discern:

- the market cost of loss. Agricultural crops that cannot be sold because they are contaminated represent an amount of money foregone.
- the market cost of repair. Damage to buildings can be expressed by the cost that is needed to restore the building.
- the market cost of replacement. Severely damaged buildings can be expressed by the cost that is needed to construct a new building.
- the market cost of being out-of-service. Damaged equipment, or broken infrastructure which impairs the supply of materials leads to halting industrial production, and thereby to a loss of turnover.

Clearly, the market approaches depend on the availability of prices for the object that is damaged, of the cost involved in repairing it, or of the estimated loss of turnover. As such, it will be possible to use this approach for man-made objects and man-driven activities.

The market-based values are not available for natural objects, such as lakes and biodiversity. It also cannot be used for man-related issues for which no market price is available, such as works of art or human life. Therefore, non-market valuation is also used to estimate damage costs. A few examples:

- There are numerous studies that attempt to estimate the economic value of biodiversity. Such studies can then be used to derive the loss of economic value from a decrease of biodiversity.

[1] Occasionally, more sophisticated approaches have been published. For instance, Bosello et al. (2006) use a general equilibrium model to model health impacts.

- Cultural heritage, such as a cathedral or a pyramid, have no market value as such: they are not for sale. But they clearly represent an economic value.

Non-market valuation can also start from many different angles, and proceed with different methods. We mention a few (Birol et al, 2006; Damigos, 2006)[2]:

- the contingent valuation method (CVM), which comprises the use of survey techniques, for instance to ask people's willingness to pay (WTP) for conserving a certain aspect of the environment;
- the hedonic pricing (HP) model, to derive the apparent value of a certain aspect of the environment by comparing house prices or job wages with and without that aspect;
- the travel cost method (TCM), which derives the apparent value of a certain aspect of the environment by investigating the amount of money people spend to enjoy this aspect.

Many studies have been with respect to the value of statistical life, which represents the apparent monetary value of a human life. Such data are of interest in health care decisions (e.g., is it justified to offer a medical treatment of a million euro to an ill person?) and in life insurance decisions. Other applications concern, for instance, the non-market value of noise: what should a government pay to compensate people living nearby an airport, or what is acceptable to spend in constructing noise-free houses?

Numerous studies have been published in which the value of environmental assets or the monetarized loss of damage to such an asset has been established. For instance, Brander et al. (2006) published a literature survey of 190 studies on wetland valuation, De Blaeij et al. (2003) summarize studies with 95 estimates of the value of statistical life, and so do Viscusi & Aldy (2003) for another 100 estimates of the value of statistical life. Nunes & Van den Bergh (2001) give a long list of biodiversity-related valuation studies. McComb et al. (2006) provide an overview of databases with valuation estimates. In other words, there is not a lack of data here.

But it is unclear which data is useful for which type of purpose. First of all, there is the choice highlighted above: cost of loss, repair, replacement, willingness to pay, hedonic prices, travel costs, etc. And even within one option, there is choice. For instance, it has repeatedly been pointed out that estimates of a willingness to pay are not universal, but rather depend on the respondent's income, the initial risk level, the form of the questionnaire, and many other conditions and circumstances (Schläpfer, 2006; Viscusi & Aldy, 2003). In the estimation of the value or damage, one should also be careful to include a discussion on what counts as damage. One recent valuation study (Hylander & Goodsite (2006) estimates the damage cost of mercury emissions by correlating exposure to mercury to a decrease in intelligence (IQ), and by correlating a decrease in intelligence to a decrease in the lifetime earnings. The authors admit that this is the "only health cost calculated here". Such information is, however, of crucial importance in judging the appropriateness of any estimate for the purpose at hand.

There is a quite broad doubt on the validity of the results of stated preference methods, and in particular when the objects to be assessed are unfamiliar, for instance when it is about rare species (MacMillan et al, 2006). The plethora of methods also gives rise to controversies: when methods yield different results, which one is to be considered as reliable or better? (Urama & Hodge, 2006). Finally, there is a critique with respect to the intrinsic meaning and ethical principles of such valuation techniques (Farrell, 2003; Ackermann & Heinzerling, 2004).

[2] See Appendix A for a more detailed overview of valuation methods.

4 Use of a damage cost method in ReCiPe

Given the overall structure of the ReCiPe method, there are two additional questions to be addressed:

- Should a damage cost weighting be connected to impact categories at the midpoint or the endpoint level?
- Should a damage cost weighting be connected to impact categories that are unnormalized or that are normalized?

For the first question, it appears that the more perceptible endpoint categories are more suitable for a valuation in terms of damage. Indicators at midpoint like the climate system, or one unit or radiative forcing, are concepts for which no market value is available, and for which a valuation study may be difficult to carry out. At the endpoint, we see indicators for human life and biological species. These have extensively been researched in economic valuation studies. Nevertheless, there are also estimates of willingness to pay for global warming

There are even studies on individual pollutants, like CO, NOx, SO2, PM10 and VOC (see, e.g., Matthews & Lave, 2000). Eshet et al. (2006) gives a comparative survey of valuation studies at the level of individual pollutants. This gives quite a range of values, sometimes by two orders of magnitude. Moreover, this sometimes gives remarkable results. For instance, in one of the studies cited, the value for CO_2 is half the value for CO.

For the second question, it should be observed that economic valuation studies focus on the object to be protected itself, not on the current level of damage. Thus, it tries to estimate the intrinsic value of this object. This naturally establishes a connection with the unnormalized indicators, in their absolute units.

In the Recipe context, three endpoints are to be subject to valuation:

- human health, with the category indicator damage to human health measured in terms of DALY;
- ecosystem quality, with the category indicator damage to ecosystem diversity measured in terms of PDF*time;
- resource availability, with the category indicator damage to resource costs measured in terms of surplus costs.

Thus, damage valuations need to be found for these three endpoints. The next section will discuss these three damage areas.

5 Damage cost values

This section is split into three subsections, each one addressing one of the endpoints of ReCiPe.

5.1 Human health

The endpoint damage to human health in ReCiPe is expressed in terms of DALY (disability-adjusted life years), which represents the sum of years of life lost due to premature mortality (YLL) and years of life lost due to disability (YLD). The valuation of human health in terms of DALY is by far the most investigated one. Numerous studies have estimated the value of statistical life, and there have even been quite a few meta-analyses on that subject.

An often cited source in context of external costs is ExternE (Anonymous, 2003). It gives a value of statistical life with a European-wide value of 3.1 M€. Viscusi & Aldy (2003) find a median value of statistical life (VOSL) of about 7 million US dollar. From a VOSL-value, the cost of a DALY can be derived. Hofstetter & Müller-Wenk (2005) summarize five studies, and infer values for 1 DALY between 5,600 and 300,000 Swiss Francs, and conclude that "there is no general conversion factor between DALYs and monetary values" (p.1243). Pearce & Koundouri (2004)give DALY-to-euro factors for different cities, ranging from 88,143 euro/yr for Shanghai to 197,613 euro/yr for Manila. They suggest using a European value of 90,000 euro/yr.

De Blaeij et al. (2003, p.984) derive from 95 estimates that "the assumption that 'life' can be summarized in a single numerical value (the 'VOSL') ... is neither sound from a theoretical perspective, nor warranted on the basis of empirical analysis."

5.2 Ecosystem quality

The valuation of ecosystem quality in terms of loss of biodiversity is much less researched than the previous human health aspect. Nunes & van den Bergh (2001) distinguish four levels of ecological aspect:

- genetic diversity and bioprospecting;
- biodiversity and species preservation;
- biodiversity and natural habitat preservation;
- biodiversity, ecosystem functions and ecological services protection.

At each level, they identify a number of valuation studies and quote the estimates. However, in all these cases, the valuation is concerned with a very partial analysis. For instance, at the second level we see studies on one or two species, like the possum or the bald eagle, at the third level studies on well-defined nature areas at a certain place, and at the fourth level studies on well-defined ecological services, like soil conservation in Australia. Estimates at the level of entire global ecosystems are not available, and Nunes & van den Bergh (2001, p.218) even suggest that this is not possible, as "monetary valuation of changes of biodiversity ... requires, ... that a concrete biodiversity change scenario is formulated. ... from the review of economic valuation studies it is clear that the assessment of biodiversity values does not lead to a univocal, unambiguous monetary indicator".

Some other sources support this view. The OECD' Handbook on biodiversity valuation (Anonymous, 2002) and the website on ecosystem valuation (http://www.ecosystemvaluation.org/uses.htm) do not seem to foresee the use of economic valuation techniques for entire ecosystems at the continental or global scale.

Pretty et al. (2003) estimate damage costs for impacts on ecosystems, in this case to water bodies due to eutrophication. The damage as such is subdivided into use value and non-use value, where the use value includes aspects related to human productivity, and the non-use value addresses the change in species composition. For this latter, a value of 26,880 $/yr per species affected is derived from the UK Biodiversity, Species and Habitat Action Plans.

White et al. (2001) report WTP-value for conserving different mammal species. Values reported range between 12 $/yr for the gray wolf and 37 $/yr for the grizzly bear. It is difficult to say how this relates to the estimates from Pretty et al. (2003). The upscaling from an individual's WTP obtained in a telephone interview to a nation's or even globe's total is far from clear. In a meta-analysis on valuation of biodiversity, Nijkamp et al. (2008) report a WTP of 28.66 euro/person/yr. Again, the upscaling presents a challenge. If we take 25$/yr as a sort of average, and multiply by 7 billion (the world population), we get a value of 175 billion euro.

Costanza et al. (1997) provide an entirely different approach to the value of an ecosystem. They consider the total world's productivity, and calculate the contribution of natural sources. This is in the range of 16-54 trillion US dollar, with an average of 33 trillion US dollar, which is 1.8 times the current global GNP. One could thus extrapolate from these figures that a 1% loss of global ecosystem function would be associated with a damage of 330 billion US dollar. Obviously, this figure includes ecosystem services as a total, not only biodiversity. If we convert the value roughly into 25 trillion euro, we see that the 175 billion for the WTP of biodiversity makes up less than 1% of this. Indeed, the major flows of nutrients, water and energy are to a large extent independent of biodiversity as such.

Azqueta & Sotelsek (2007) discuss many conceptual problems related to such a valuation of natural capital. They conclude that "estimates of the natural capital of a given region ... should be taken very carefully. ... if they are meant to inform policy decision making processes ... the problems mentioned above will appear immediately, calling for a much more complex exercise than just adding different layers of value, each corresponding to some specific service, to a given piece of territory" (p.29).

5.3 Resource availability

The valuation of resource availability in terms of loss of increased costs for resource extraction is easier than the other ones. The metric surplus energy cost is expressed in $. As such, one may carry it directly over from endpoint indicator to damage cost. After all, the $-value is a marginal cost due to extraction, and thus could be considered as a damage to future profitability.

6 Using damage costs: best practice and recommendations

The overall picture emerges that much is unclear:

- there are various interpretations of what we mean with damage costs;
- there are various ways to estimate these costs by non-market valuation techniques;
- there is a large range in the results reported in the case studies.

Even so, many theoretical studies express sincere doubt on the usefulness and robustness of the use of results from WTP and other valuation studies.

Nevertheless, there are cases when something is better than nothing. For those cases, we report Table 1 below.

Table 1. Summary of possible weighting factors on the basis of damage costs.

Endpoint	Weighting factor	Unit
human health	60,000	$/yr
ecosystem quality	175,000,000,000	$/yr
resource availability	1	$/$

A final word on weighting. ISO 14044 (p.23) states the following: "Weighting ... shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public." Whatever one may think of this, the speculative nature of Table 1, and the whole issue about presenting three alternative approaches toward weighting within the present project, it appears to be god practice to use sensitivity and uncertainty analyses, and to use different methods. This applies to many topics in LCA, such as allocation and cut-off, but it applies emphatically to weighting.

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A Overview of the main valuation methods[3]

A.1 Stated preference methods (SP)

SP are direct methods enabling estimations of economic values for a wide range of intangible commodities based on individuals' preferences, including contingent valuation method (CVM) and choice modeling. SP methods are mainly used in SWM context to assess individuals' WTP for a specific degree of improvement in their welfare level caused by air/water/land pollution level and disamenity impacts as well, related to different waste management options:

- Contingent valuation method (CVM) (market creation method) is a method in which people are asked directly through a survey to state their WTP for a benefit or to avoid a cost, or conversely on their WTA to forego a benefit or tolerate a cost, regarding a specific hypothetical policy. Yet, they are assumed to behave as though they were in a real market. Econometric techniques are then applied to the survey results to derive the average bid value, i.e. the average WTP.
- Choice modeling methods (Conjoint analysis) represent a broad term of survey methods asking individuals to rank/rate/choose alternatives rather than explicitly express a WTP or WTA. The techniques (based on marketing research tools) rely on the idea that any good can be described in terms of its attributes, and the levels that these take. Changing attribute levels will essentially result in a different 'good' being produced and the techniques focus on the value of such changes in attributes. A baseline status quo alternative is usually included to help establish the other alternatives in relation to the respondent's actual experience. It is generally assumed that choice modeling approaches are preferred over CVM in contexts where it is important to value individual attributes.

A.2 Revealed preference methods (RP)

RP are indirect methods inferring preferences and implicit value for externalities from actual market observations. Preferences are revealed indirectly when individuals purchase marketed goods and services that are supposed to solve/reduce the associated environmental problem:

- Hedonic price method (HPM) (/Surrogate markets method) relies on the notion that people derive utility from various physical and environmental attributes of a house. The value individuals place on an environmental attribute (e.g. air quality near a landfill/incinerator) is obtained from differences in housing prices at various distances away from the sites. HPM has also been applied to labor market in valuation of work-related risk in Hedonic wage studies, giving an indication of the value that people ascribe to their lives.
- Averting behavior method assumes that marketed goods can act as substitutes for environmental goods because households spend money to offset environmental impacts. For instance, expenditures such as water filters in the vicinity of a landfill can be used to value clean water and thus can represent the value of the damage to groundwater caused by landfill leachate.
- Cost of illness method (COI) estimates external costs through changes in private and public expenditures on medical commodities and earnings lost due to days not worked resulting from the suffering from various impacts related to noxious facilities.
- Health production function (HPF) is a popular way of calculating the relative effects that a pollutant has on health. The measurement widely used is the mortality rate. The

[3] Taken with small modifications from Eshet et al. (2006), p.359-360.

function depicts health as a good or output that is a function of various inputs including the environmental factor. The approach assumes that increases in the purchases of health-care goods and services decrease the purchases of other goods and services, when controlling for household income constraints. In fact, HPF methods comprise elements both from averting behavior methods and from COI methods, and it is a more comprehensive approach.

- Court-decision assessment is an alternative indirect-method presented in a disamenity-valuation study. The method is based on observation of actual expenditure involved in citizens' legal suits against noxious facilities. These costs include, inter-alia, various government or municipality costs engaged in the investigation of a complaint, costs of the activities of Citizens groups, environmental lawyers' fees and advocacy costs of the companies.
- Travel cost method has been founded especially for monetary valuation of recreational sites. The approach is based on the fact that usually a trip to a recreational site requires an individual to incur costs in terms of travel, entry fees, on-site expenditures, and time. These costs are used as a proxy for the use value of the site and for changes in its quality. Apparently, and according to existing literature, this method has no place in valuing SWM externalities.